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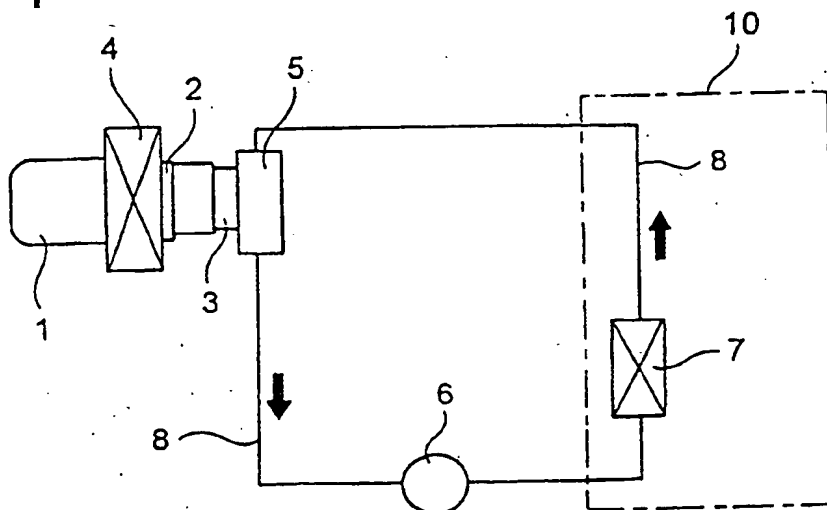
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(54) **STIRLING COOLING DEVICE, COOLING CHAMBER, AND REFRIGERATOR**

(57) In a Stirling cooling apparatus, a refrigerant is circulated within a refrigerant circulation circuit in such a way that the refrigerant receives cold, as latent heat, from a Stirling chiller and then releases the cold, by ab-

sorbing heat of vaporization, as it vaporizes in an evaporator, thereby cooling the inside of a refrigerator chamber. As the refrigerant, carbon dioxide, a natural refrigerant, can be suitably used.

**FIG. 1**



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## Description

### Technical field

[0001] The present invention relates to a cooling apparatus, cooler, and refrigerator employing a Stirling chiller.

### Background art

[0002] As is well known, conventionally, refrigerants based on CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons) have been in wide use as working fluids in chilling and air-conditioning systems. However, refrigerants based on CFCs have already been totally banned, and the use of refrigerants based on HCFCs is regulated by the international treaty for the protection of the ozone layer. On the other hand, newly developed refrigerants based on HFCs (hydrofluorocarbons) do not destroy the ozone layer, but are powerful global warming substances having global warming coefficients as high as several hundred to several thousand times that of carbon dioxide. Thus, these are also targets of emission regulation.

[0003] For this reason, as an alternative technology to the vapor-compression cooling cycle which uses a refrigerant mentioned above as a working fluid, research has been done extensively on Stirling chillers, which exploits the reverse Stirling cycle to produce cold.

[0004] A conventional Stirling cooling apparatus, disclosed in U. S. Patent No. 5,927,079, will be described with reference to Fig. 7. Reference numeral 20 represents a Stirling chiller; reference numerals 21 and 22 respectively represent a heat releaser portion and a radiator of the Stirling chiller 20; reference numeral 23 represents a water pump for the cooling water circulated to cool the heat releaser portion 21; reference numeral 24 represents a refrigerant cooler portion for cooling a secondary refrigerant with the cold obtained from the Stirling chiller 20; reference numeral 25 represents a refrigerant pipe through which the secondary refrigerant is circulated so that the cold is transferred to inside a cooling chamber 27; and reference numeral 26 represents a refrigerant pump for circulating the secondary refrigerant through the refrigerant pipe 25.

[0005] In this arrangement, when the Stirling chiller 20, the water pump 23, and the refrigerant pump 26 are driven, the high-temperature waste heat that is transmitted to the heat releaser portion 21 of the Stirling chiller 20 is transferred by the water to the radiator 22, where the heat is released to the surrounding space. Simultaneously, the cold obtained from the Stirling chiller 20 is transferred, by the secondary refrigerant circulating through the refrigerant pipe 25, to inside the cooling chamber 27.

[0006] The transfer of the cold produced by the Stirling chiller 20 to the cooling chamber 27 is achieved by exploiting the sensible heat of the secondary refrigerant,

such as ethanol free from phase change. Thus, whereas in the refrigerant cooler portion 24 the secondary refrigerant is cooled and thus its temperature falls, in the cooling chamber 27 it absorbs heat and thus its temperature rises. The refrigerant, having its temperature raised while passing through the refrigerant pipe 25, then returns to the refrigerant cooler portion 24 by the action of the refrigerant pump 26. This cycle is repeated, and as a result the inside of the cooling chamber 27 is cooled to lower and lower temperature.

[0007] In this arrangement, however, since the cold is transferred by exploiting the sensible heat of the secondary refrigerant, temperature difference arises within the refrigerant pipe 25, leading to poor heat transmission efficiency. Moreover, ethanol used as the secondary refrigerant has a low flash point (about 12.8 °C) and is highly volatile, requiring care in its handling. Furthermore, the viscosity of ethanol at temperatures from -40 to -50 °C is as high as about one hundred times that of water at ordinary temperatures. This increases the load on the refrigerant pump 26, and thus reduces the energy efficiency of the Stirling cooling apparatus.

### Disclosure of the invention

[0008] An object of the present invention is to provide a Stirling cooling apparatus or cooler that complies with the regulation of refrigerants based on HCFCs and HFCs and that offers improved cooling efficiency by exploiting latent heat. Another object of the present invention is to provide a large-capacity, low-power-consumption refrigerator that offers good heat exchange efficiency.

[0009] To achieve the above objects, according to one aspect of the present invention, a Stirling cooling apparatus is provided with: a Stirling chiller having a high-temperature portion whose temperature rises as the Stirling chiller is operated and a low-temperature portion whose temperature falls as the Stirling chiller is operated; an evaporator provided integrally with or separately from the Stirling chiller; and a refrigerant circulation circuit for transferring cold produced by the low-temperature portion to the evaporator by means of a refrigerant circulated between the low-temperature portion and the evaporator by a refrigerant circulation means. Here, the refrigerant is a natural refrigerant that liquefies in the low-temperature portion and vaporizes in the evaporator.

[0010] In this configuration, when the Stirling chiller is driven, the cold produced by the low-temperature portion is collected as latent heat by the refrigerant circulating around the refrigerant circulation circuit. The refrigerant then vaporizes in the evaporator, absorbing heat of vaporization and thereby cooling the surrounding air.

[0011] In this case, as the natural refrigerant, carbon dioxide can suitably be used, which is inexpensive and harmless to the environment and to humans. However,

as compared with other refrigerants, carbon dioxide has a low critical point (about 31 °C) and a high critical pressure (about 74 bar). Thus, the refrigerant circulation means needs to have sufficiently high resistance to pressure and hermeticity.

[0012] The refrigerant is circulated around the refrigerant circulation circuit by the refrigerant circulation means so as to transfer the cold to the evaporator. Here, if the refrigerant has not been cooled sufficiently to a supercooled state by the low-temperature portion, i.e. if the temperature of the refrigerant after passing through the condenser is near its boiling point, when the refrigerant receives power as the refrigerant circulation means (for example, a pump) is driven, part of the refrigerant may vaporize as a result of a local rise in the temperature thereof that arises around the power transmission mechanism (hereinafter, this phenomenon will be referred to as "cavitations").

[0013] To cope with this, in the present invention, the refrigerant is cooled to a predetermined supercooled state by the low-temperature portion. Thus, even if there arises a partial rise in the temperature of the refrigerant around the power transmission mechanism of the refrigerant circulation means, no part of the refrigerant vaporizes. In this way, cavitation is prevented.

[0014] In the Stirling cooling apparatus according to the present invention, in the path within the refrigerant circulation circuit which the refrigerant takes after flowing out of the low-temperature portion before flowing into the refrigerant circulation means, a gas-liquid separator may be arranged that separates the refrigerant into a gas phase and a liquid phase and that permits only the refrigerant in the liquid phase to be supplied to the refrigerant circulation means.

[0015] In this configuration, the refrigerant that has flown out of the low-temperature portion in the form of a gas-liquid mixture is then separated into two phases, i.e. a gas phase and a liquid phase, by the gas-liquid separator so that only the refrigerant in the liquid phase flows into the refrigerant circulation means. This helps stabilize the operation of the refrigerant circulation means.

[0016] In the Stirling cooling apparatus according to the present invention, the refrigerant circulation means may be composed of a gas-liquid separator, which is arranged in a path within the refrigerant circulation circuit which the refrigerant takes after flowing out of the low-temperature portion before flowing into the refrigerant circulation means and in a position higher than the evaporator, and which separates the refrigerant into a gas phase and a liquid phase and permits only the refrigerant in the liquid phase to be supplied to the refrigerant circulation means. Here, the difference in specific gravity between the refrigerant in the liquid phase at the outlet of the gas-liquid separator and the refrigerant inside the evaporator is exploited as a power source for circulating the refrigerant.

[0017] In this configuration, when the Stirling chiller is

driven, the cold produced by the low-temperature portion is collected as latent heat by the refrigerant circulating around the refrigerant circulation circuit. The refrigerant then vaporizes in the evaporator, absorbing heat of vaporization and thereby cooling the surrounding air. In this case, even without a circulation pump, the refrigerant circulates around the refrigerant circulation circuit spontaneously by exploiting the difference in specific gravity between the refrigerant in different phases.

[0018] When this Stirling cooling apparatus is incorporated in a refrigerator, the cold produced by the low-temperature portion of the Stirling chiller is transferred by the refrigerant circulating around the refrigerant circulation circuit so as to efficiently cool the inside of the refrigerator chamber.

[0019] According to another aspect of the present invention, in a refrigerator incorporating a Stirling chiller, a low-temperature-side evaporator for releasing cold to inside a refrigerator chamber is arranged in a position lower than a low-temperature portion of the Stirling chiller which produces the cold; a circuit is arranged in such a way that a refrigerant is circulated between the low-temperature-side evaporator and the low-temperature portion; and the refrigerant liquefies by absorbing the cold in the low-temperature portion, then flows to the low-temperature-side evaporator by exploiting the difference in height between the low-temperature portion and the low-temperature-side evaporator, then vaporizes by releasing the cold inside the low-temperature-side evaporator, and then flows in a vaporized state back to the low-temperature portion.

[0020] According to another aspect of the present invention, in a refrigerator incorporating a Stirling chiller, a high-temperature-side condenser for releasing heat to outside a refrigerator chamber is arranged in a position higher than a high-temperature portion of the Stirling chiller which produces the heat; a circuit is arranged in such a way that a refrigerant is circulated between the high-temperature-side condenser and the high-temperature portion; and the refrigerant vaporizes by absorbing the heat in the high-temperature portion, then flows in a vaporized state to the high-temperature-side condenser, then liquefies by releasing the heat inside the high-temperature-side condenser, and then flows back to the high-temperature portion by exploiting the difference in height between the high-temperature-side condenser and the high-temperature portion.

[0021] According to another aspect of the present invention, in a refrigerator incorporating a Stirling chiller, a low-temperature-side evaporator for releasing cold to inside a refrigerator chamber is arranged in a position lower than a low-temperature portion of the Stirling chiller which produces the cold; a circuit is arranged in such a way that a first refrigerant is circulated between the low-temperature-side evaporator and the low-temperature portion; the first refrigerant liquefies by absorbing the cold in the low-temperature portion, then flows to the low-temperature-side evaporator by exploiting the dif-

ference in height between the low-temperature portion and the low-temperature-side evaporator, then vaporizes by releasing the cold inside the low-temperature-side evaporator, and then flows in a vaporized state back to the low-temperature portion; a high-temperature-side condenser for releasing heat to outside the refrigerator chamber is arranged in a position higher than a high-temperature portion of the Stirling chiller which produces the heat; a circuit is arranged in such a way that a second refrigerant is circulated between the high-temperature-side condenser and the high-temperature portion; and the second refrigerant vaporizes by absorbing the heat in the high-temperature portion, then flows in a vaporized state to the high-temperature-side condenser, then liquefies by releasing the heat inside the high-temperature-side condenser, and then flows back to the high-temperature portion by exploiting the difference in height between the high-temperature-side condenser and the high-temperature portion

[0022] In these refrigerators configured as described above, the use of latent heat obtained through vaporization and liquefaction of the refrigerant contributes to better heat transmission efficiency than when sensible heat is exploited. Thus, cold is efficiently transferred to inside the refrigerator chamber, or heat is efficiently released to outside the refrigerator chamber. This helps enhance the heat exchange efficiency of refrigerators.

[0023] Moreover, the condenser and the evaporator can be formed in the desired sizes. This makes it possible to efficiently transfer the heat in the low-temperature and high-temperature portions, of which the sizes are limited in consideration of the efficiency of the reverse Stirling cycle, to air, which has low thermal conductivity. This helps realize large-capacity refrigerators.

[0024] Moreover, the refrigerant is circulated by exploiting the difference in height, without the use of external power prepared specially for the circulation of the refrigerant. This helps realize low-power-consumption refrigerators.

[0025] In the refrigerators according to the present invention, a gas-liquid separator may be provided additionally. This helps increase the flow rate of the refrigerant circulated.

[0026] In the refrigerators according to the present invention, as the refrigerant, carbon dioxide or water may be used, which is a non-flammable, non-toxic natural refrigerant. This helps realize refrigerators friendly to humans and to the global environment.

[0027] In the refrigerators according to the present invention, the height of the refrigerators may be used effectively to arrange the low-temperature-side and high-temperature-side heat exchanger portions. Moreover, the refrigerator chamber may be divided into an upper section serving as a refrigerator compartment, a middle section serving as a vegetables compartment, and a lower section serving as a freezer compartment. This contributes to effective use of the cold air inside the refrigerator chamber.

## Brief description of drawings

[0028]

Fig. 1 is a diagram schematically showing the configuration of the Stirling cooling apparatus of a first embodiment of the invention. Fig. 2 is a diagram schematically showing the configuration of the Stirling cooling apparatus of a second embodiment of the invention. Fig. 3 is a diagram schematically showing the configuration of the Stirling cooling apparatus of a third embodiment of the invention. Fig. 4 is a diagram schematically showing the configuration of the refrigerator of a fourth embodiment of the invention. Fig. 5 is a conceptual diagram of the chiller system of the refrigerator of a fifth embodiment of the invention. Fig. 6 is a diagram schematically showing the configuration of the refrigerator of a sixth embodiment of the invention. Fig. 7 is a diagram schematically showing the configuration of an example of a conventional Stirling cooling apparatus.

## Best mode for carrying out the invention

[0029] First, a first embodiment of the present invention will be described with reference to the relevant drawing. Fig. 1 is a diagram schematically showing the configuration of the Stirling cooling apparatus (hereinafter referred to as the "chiller system" also) of the first embodiment. In Fig. 1, reference numeral 1 represents a Stirling chiller; reference numeral 2 represents a high-temperature portion whose temperature rises as the Stirling chiller 1 is operated; reference numeral 3 represents a low-temperature portion that produces cold as the Stirling chiller 1 is operated; reference numeral 4 represents a high-temperature-side heat exchanger for releasing heat from the high-temperature portion to the surrounding space. Moreover, next to the Stirling chiller 1, a cooling chamber 10 is arranged. In a space secured inside a heat-insulation wall so as to communicate with the space inside the cooling chamber 10, an evaporator 7 is provided.

[0030] Next to the low-temperature portion 3, a condenser 5 is provided. The condenser 5, a circulation pump 6, and the evaporator 7 are connected to one another successively with refrigerant piping 8 to form a refrigerant circulation circuit. In the figure, arrows indicate the direction of the flow of the refrigerant. In this embodiment, as the refrigerant is used carbon dioxide, which is a natural refrigerant.

[0031] The Stirling chiller 1 has, as a working fluid, helium or nitrogen sealed in a cylinder, and has one power piston (not shown) and one displacer (not shown) arranged parallel to an axis common to them. When the power piston is driven with a linear motor (not shown), the power piston and the displacer reciprocate along the same axis inside the same cylinder with a predeter-

mined phase difference. The Stirling chiller 1 used in this embodiment is not limited to a Stirling chiller of the type in which a power piston is driven with a linear motor as described above, but may be a Stirling chiller of any other type.

[0032] When the linear motor is driven, on the principle described above, waste heat (hereinafter referred to simply as "heat" also) is transferred to the high-temperature portion 2 of the Stirling chiller 1, raising the temperature of the high-temperature portion 2, and simultaneously cryogenic cold is produced in the low-temperature portion 3. Then, in the high-temperature-side heat exchanger 4 arranged so as to be in contact with the high-temperature portion 2, the waste heat is released out of the Stirling chiller 1 by air or water used as a heat carrier.

[0033] Simultaneously, the circulation pump 6 is also driven so that the refrigerant is circulated around the refrigerant circulation circuit in the direction indicated by the arrows. Since carbon dioxide is used as the refrigerant, the circulation pump 6 is designed to be resistant to and hermetic up to a pressure of at least 74 bar. In this refrigerant circulation circuit, the refrigerant is condensed by the condenser 5 fitted to the low-temperature portion 3, and thereby the cold originating from the low-temperature portion 3 is stored mainly in the form of latent heat in the refrigerant.

[0034] The refrigerant, having been condensed by the condenser 5 and now in a low-temperature, liquid state, then flows through the refrigerant piping 8 by the action of the circulation pump 6 so as to flow into the evaporator 7. In the evaporator 7, the refrigerant vaporizes. As the refrigerant vaporizes, it absorbs heat of vaporization from the surroundings, and thereby transfers cold to inside the cooling chamber 10. The refrigerant, having vaporized in the evaporator 7 and now in a gaseous state, then flows through refrigerant piping 8 back to the condenser 5. As long as the circulation pump 6 is driven, this cycle of events is repeated.

[0035] Here, if cavitation occurs in the circulation pump 6 in the refrigerant circulating around the refrigerant circulation circuit, there arise problems such as air bubbles corroding and degrading the circulation pump 6 and the flow rate of the refrigerant becoming unstable. Thus, to prevent cavitation, it is essential to set the loading amount and mass flow rate of the refrigerant appropriately so that a predetermined supercooled state is achieved in the condenser 5. Specifically, the loading amount of the refrigerant is so determined that, at operating temperature, the refrigerant in the liquid phase completely fills at least the total volume inside that portion of the refrigerant circulation circuit, i.e. mainly the refrigerant piping 8, which starts at the point where the refrigerant is completely liquefied by the condenser 5, runs through the circulation pump 6, and ends at the entrance of the evaporator 7.

[0036] Moreover, by controlling the mass flow rate of the refrigerant according to the cooling capacity of the

Stirling chiller 1, it is possible to achieve the desired supercooled state in the refrigerant condensed by the condenser 5 at operating temperature. By maintaining such a supercooled state, it is possible to prevent cavitation resulting from vaporization of the refrigerant in the circulation pump 6 even if pressure loss or heat absorption occurs in the refrigerant flowing through that portion of the refrigerant piping 8 leading from the exit of the condenser 5 to the exit of the circulation pump 6, and thereby maintain normal circulation of the refrigerant.

[0037] Next, a second embodiment of the present invention will be described with reference to the relevant drawing. Fig. 2 is a diagram schematically showing the configuration of the Stirling cooling apparatus of this embodiment. In Fig. 2, such members as are common to the cooling apparatus of the first embodiment shown in Fig. 1 and described above are identified with the same reference numerals, and their detailed explanations will not be repeated.

[0038] In this embodiment, the refrigerant circulation circuit is formed by connecting a condenser 5, a gas-liquid separator 9, a circulation pump 6, and an evaporator 7 to one another successively with refrigerant piping 8. In the figure, arrows indicate the direction of the flow of the refrigerant. In this embodiment, carbon dioxide is used as the refrigerant. Moreover, the gas-liquid separator 9 is arranged on the downstream side of the condenser 5 in the refrigerant circulation circuit, and is placed in a position lower than the condenser 5 and higher than the circulation pump 6.

[0039] In the figure, arrows indicate the direction of the flow of the refrigerant. In this embodiment, carbon dioxide is used as the refrigerant. The configuration and operation of the Stirling chiller 1 shown in Fig. 2 are the same as in the first embodiment described above, and therefore its explanations will not be repeated.

[0040] When the linear motor (not shown) is driven, on the principle described earlier, waste heat is transferred to the high-temperature portion 2 of the Stirling chiller 1, raising the temperature of the high-temperature portion 2, and simultaneously cryogenic cold is produced in the low-temperature portion 3. Then, in the high-temperature-side heat exchanger 4 arranged so as to be in contact with the high-temperature portion 2, the waste heat is released out of the Stirling chiller 1 by air or water used as a heat carrier.

[0041] Simultaneously, the circulation pump 6 is also driven so that the refrigerant is circulated around the refrigerant circulation circuit in the direction indicated by the arrows. Since carbon dioxide is used as the refrigerant, the circulation pump 6 is designed to be resistant to and hermetic up to a pressure of at least 74 bar. In this refrigerant circulation circuit, the refrigerant is condensed by the condenser 5 fitted to the low-temperature portion 3, and thereby the cold originating from the low-temperature portion 3 is stored mainly in the form of latent heat in the refrigerant.

[0042] The refrigerant, having been condensed by the

condenser 5 and now in a low-temperature, partly gaseous and partly liquid state, then flows into the gas-liquid separator 9 arranged on the downstream side of the condenser 5. In the gas-liquid separator 9, the refrigerant is separated into a gas phase and a liquid phase. The separated refrigerant in the liquid phase is then compressed by the circulation pump 6, and then flows through the refrigerant piping 8 into the evaporator 7. In the evaporator 7, the refrigerant vaporizes. As the refrigerant vaporizes, it absorbs heat of vaporization from the surroundings, and thereby transfers cold to inside the cooling chamber 10. The refrigerant, having vaporized in the evaporator 7 and now in a gaseous state, then flows through the refrigerant piping 8 back to the condenser 5. As long as the circulation pump 6 is driven, this cycle of events is repeated.

[0043] Here, if cavitation occurs in the circulation pump 6 in the refrigerant circulating around the refrigerant circulation circuit, there arise problems such as air bubbles corroding and degrading the circulation pump 6 and the flow rate of the refrigerant becoming unstable. Thus, in this embodiment, to prevent cavitation, special consideration is given to where to place the gas-liquid separator 9.

[0044] Specifically, the gas-liquid separator 9 is arranged on the downstream side of the condenser 5 in the refrigerant circulation circuit, and is placed in a position lower than the condenser 5 and higher than the circulation pump 6. This permits that portion of the refrigerant piping 8 leading from the liquid surface inside the gas-liquid separator 9 to the entrance of the circulation pump 6 to be filled with the refrigerant in the liquid phase in the form of an upright column. The pressure of this column of the refrigerant prevents cavitation in the circulation pump 6, and thereby ensures normal circulation of the refrigerator.

[0045] Next, a third embodiment of the present invention will be described with reference to the relevant drawing. Fig. 3 is a diagram schematically showing the configuration of the Stirling cooling apparatus of this embodiment. In Fig. 3, such members as are common to the cooling apparatus of the first embodiment shown in Fig. 1 and described earlier are identified with the same reference numerals, and their detailed explanations will not be repeated.

[0046] In this embodiment, the refrigerant circulation circuit is formed by connecting a condenser 5, a gas-liquid separator 9, and an evaporator 7 to one another successively with refrigerant piping 8a and 8b. In the figure, arrows indicate the direction of the flow of the refrigerant. In this embodiment, carbon dioxide is used as the refrigerant. Moreover, the gas-liquid separator 9 is arranged on the downstream side of the condenser 5 in the refrigerant circulation circuit, and is placed in a position lower than the condenser 5 and higher than the evaporator 7.

[0047] In the figure, arrows indicate the direction of the flow of the refrigerant. In this embodiment, carbon

dioxide is used as the refrigerant. The configuration and operation of the Stirling chiller 1 shown in Fig. 2 are the same as in the first embodiment described above, and therefore its explanations will not be repeated.

[0048] When the linear motor (not shown) is driven, on the principle described earlier, waste heat is transferred to the high-temperature portion 2 of the Stirling chiller 1, raising the temperature of the high-temperature portion 2, and simultaneously cryogenic cold is produced in the low-temperature portion 3. Then, in the high-temperature-side heat exchanger 4 arranged so as to be in contact with the high-temperature portion 2, the waste heat is released out of the Stirling chiller 1 by air or water used as a heat carrier.

[0049] In this refrigerant circulation circuit, the refrigerant is condensed by the condenser 5 fitted to the low-temperature portion 3, and thereby the cold originating from the low-temperature portion 3 is stored mainly in the form of latent heat in the refrigerant. The refrigerant, having been condensed by the condenser 5 and now in a low-temperature, partly gaseous and partly liquid state, then flows into the gas-liquid separator 9 arranged on the downstream side of the condenser 5. In the gas-liquid separator 9, the refrigerant is separated into a gas phase and a liquid phase.

[0050] The separated refrigerant in the liquid phase then flows through the refrigerant piping 8a into the evaporator 7. In the evaporator 7, the refrigerant vaporizes. As the refrigerant vaporizes, it absorbs heat of vaporization from the surroundings, and thereby transfers cold to inside the cooling chamber 10. The refrigerant, having vaporized in the evaporator 7 and now in a gaseous state, then flows through the refrigerant piping 8b back to the condenser 5. This cycle of events is repeated.

[0051] In this configuration, the gas-liquid separator 9 is arranged on the downstream side of the condenser 5 in the refrigerant circulation circuit, and is placed in a position lower than the condenser 5 and higher than the evaporator 7. As a result, the refrigerant in the liquid phase fills the piping 8a leading to the entrance of the evaporator 7, and on the other hand the refrigerant in the gas phase flows through the refrigerant piping 8b leading from the exit of the evaporator 7 to the condenser 5. Thus, the refrigerant circulates around the refrigerant circulation circuit spontaneously by exploiting the difference in specific density between the refrigerant in the liquid and gas phases.

[0052] In this way, this configuration eliminates the need for a circulation pump 6 for forcibly circulating the refrigerant around the refrigerant circulation circuit. This helps reduce the costs accordingly and realize a energy-saving Stirling cooling apparatus.

[0053] Next, a fourth embodiment of the present invention will be described with reference to the relevant drawing. Fig. 4 is a sectional view of the refrigerator of this embodiment. It is to be understood that, although a refrigerator incorporating the Stirling cooling apparatus

of the third embodiment described above is taken up as an example in the following description, the configuration of this embodiment applies also to a refrigerator incorporating a Stirling cooling apparatus in which the refrigerant is forcibly circulated by the action of a circulation pump as in the first and second embodiments.

[0054] As Fig. 4 shows, in an upper rear portion of the refrigerator 17, a Stirling chiller 1 is arranged so as to lay horizontally, with a condenser 5 fitted to the low-temperature portion 3 (not shown) of the Stirling chiller 1. Moreover, a gas-liquid separator 9 is provided in a position lower than the condenser 5. On the other hand, in a lower rear portion of the refrigerator 17, an evaporator 7 is arranged. The condenser 5, the gas-liquid separator 9, and the evaporator 7 are connected to one another successively with refrigerant piping 8a and 8b to form a refrigerant circulation circuit.

[0055] The refrigerant in the liquid phase separated by the gas-liquid separator 9, by falling spontaneously, flows down through the refrigerant piping 8a, which leads from the exit of the gas-liquid separator 9 to the entrance of the evaporator 7, into the evaporator 7. Thus, the refrigerant in the liquid phase fills the refrigerant piping 8a. On the other hand, the refrigerant in the gas phase vaporized in the evaporator 7 flows up through the refrigerant piping 8b, which leads from the exit of the evaporator 7 to the entrance of the condenser 5.

[0056] In this way, the pressure resulting from the difference between the gravity acting on the refrigerant in the liquid phase inside the refrigerant piping 8a and the gravity acting on the refrigerant in the gas phase inside the refrigerant piping 8b causes the refrigerant to flow upward through the refrigerant piping 8a and downward through the refrigerant piping 8b. Thus, even without a means, such as a circulation pump, for forcibly circulating the refrigerant, the refrigerant can be circulated spontaneously around the refrigerant circulation circuit.

[0057] The refrigerant condenses by releasing heat through the condenser 5 to the high-temperature portion 2 (not shown) of the Stirling chiller 1, and vaporizes by absorbing heat from the cold air circulating inside the refrigerator chamber of the refrigerator 17. The cold air cooled by the evaporator 7 is then blown into the refrigerator chamber by a cold air circulation fan 13 as indicated by arrows, and thereby the space inside the refrigerator chamber is cooled. In this way, the cold produced by the Stirling chiller 1 is transferred to the refrigerator 17 through the refrigerant circulation circuit formed by the condenser 5, the gas-liquid separator 9, and the evaporator 7.

[0058] The air outside the refrigerator 17 is introduced into the refrigerator 17 through an air suction duct 14 and is exhausted out of the refrigerator 17 through an air exhaust duct 15 by a fan 12. Meanwhile, by the air passing through the air suction duct 14 and the air exhaust duct 15, the waste heat transmitted to the high-temperature portion 2 of the Stirling chiller 1 is released

out of the refrigerator 17 through the high-temperature-side heat exchanger 4.

[0059] Part of the moisture contained in the cold air circulating inside the refrigerator chamber condenses and forms water droplets on the surface of the evaporator 7. These water droplets drain through a drain outlet 16 and collect in a drain pan (not shown). Periodically, the drain pan is taken out, and the water collected therein is disposed of.

[0060] Next, a fifth embodiment of the present invention will be described with reference to the relevant drawing. Fig. 5 is a conceptual diagram of the chiller system of the refrigerator of this embodiment. In Fig. 5, such members as are common to the cooling apparatus of the first embodiment shown in Fig. 1 and described earlier are identified with the same reference numerals, and their detailed explanations will not be repeated.

[0061] This chiller system is composed of a Stirling chiller 1 having a low-temperature portion 3 and a high-temperature portion 2, a low-temperature-side heat exchanger portion 30, and a high-temperature-side heat exchanger portion 31. The low-temperature-side heat exchanger portion 30 is a circulation circuit composed of a low-temperature-side condenser 32 formed by a copper pipe wound around the low-temperature portion 3, a low-temperature-side gas-liquid separator 9 connected to the low-temperature-side condenser 32 by a copper pipe 33 and arranged in a position lower than the low-temperature portion 3, a low-temperature-side evaporator 7 connected to the bottom of the gas-liquid separator 9 by a copper pipe 34 and arranged in a still lower position, and a copper pipe 35 connecting together the evaporator 7 and the low-temperature-side condenser 32. As a refrigerant, carbon dioxide is sealed in this circuit.

[0062] On the other hand, the high-temperature-side heat exchanger portion 31 is a circulation circuit composed of a high-temperature-side evaporator 36 formed by a copper pipe wound around the high-temperature portion 2, a high-temperature-side condenser 38 connected to the evaporator 36 by a copper pipe 37 and arranged in a position higher than the high-temperature portion 2, a gas-liquid separator 40 connected to high-temperature side condenser 38 by a copper pipe 39 and arranged in a position lower than the high-temperature-side condenser 38 and higher than the high-temperature portion 2, and a copper pipe 41 connecting together the bottom of the gas-liquid separator 40 and the evaporator 36. As a refrigerant, water is sealed in this circuit. In the figure, arrows indicate the direction of the flow of the refrigerants.

[0063] Next, the operation of the low-temperature-side heat exchanger portion 30 will be described. The cold generated in the low-temperature portion 3 is transmitted to the low-temperature-side condenser 32, where most of the refrigerant liquefies. The refrigerant, now in a partly liquid and partly gaseous state, then flows through the copper pipe 33 into the low-temperature

side gas-liquid separator 9 by exploiting the difference in height between the low-temperature-side condenser 32 and the low-temperature-side gas-liquid separator 9. In the gas-liquid separator 9, the refrigerant in the liquid phase collects. The refrigerant in the liquid phase then flows from the bottom of the gas-liquid separator 9 through the copper pipe 34 into the low-temperature-side evaporator 7. In the low-temperature-side evaporator 7, the refrigerant in the liquid phase exchanges the cold it has been carrying with the heat of the air inside the refrigerator chamber through the wall surface of the low-temperature-side evaporator 7. In this way, as the refrigerant in the liquid phase vaporizes, it produces cold air inside the refrigerator chamber.

**[0064]** The refrigerant, now in a vaporized state, flows through the copper pipe 35 into the low-temperature-side condenser 32 by exploiting the difference in height between the low-temperature-side evaporator 7 and the low-temperature-side condenser 32 and the difference in pressure resulting from the difference in specific gravity between the refrigerant in the gas and liquid phases. By repeating this cycle of events, even without the use of an external power for circulating the refrigerant, it is possible to transfer cold to inside the refrigerator chamber, and thus it is possible to realize a low-power-consumption refrigerator.

**[0065]** Here, the use of latent heat obtained through vaporization and liquefaction of the refrigerant contributes to better heat transmission efficiency than when sensible heat is exploited. This makes it possible to efficiently transmit the cold in the low-temperature portion 3 to the low-temperature-side evaporator 7, and thereby enhance the heat exchange efficiency of a refrigerator. Moreover, the low-temperature-side condenser 32 and the low-temperature-side evaporator 7 can be formed in the desired sizes. This makes it possible to efficiently transfer the cold in the low-temperature portion 3, of which the size is limited in consideration of the efficiency of the reverse Stirling cycle, to the air, which has low thermal conductivity, inside the refrigerator chamber. This helps realize a large-capacity refrigerator. Furthermore, as the refrigerant, carbon dioxide is used, which is a non-flammable, non-toxic natural refrigerant. This helps realize a refrigerator friendly to humans and to the global environment.

**[0066]** Next, the operation of the high-temperature-side heat exchanger portion 31 will be described. The heat produced in the high-temperature portion 2 is transmitted to the high-temperature-side evaporator 36, where the refrigerant vaporizes. The refrigerant, now in a gaseous state, then flows through the copper pipe 37 into the high-temperature-side condenser 38 by exploiting the difference in height between the evaporator 36 and the high-temperature-side condenser 38. In the high-temperature-side condenser 38, the refrigerant liquefies as it exchanges the heat it has been carrying with the air outside the refrigerator chamber through the wall surface of the high-temperature-side condenser 38.

**[0067]** The refrigerant, now in a partly liquid and partly gaseous state, then flows from the bottom of the high-temperature-side condenser 38 through the copper pipe 39 into the high-temperature-side gas-liquid separator 40, where the refrigerant in the liquid phase collects. The refrigerant in the liquid phase then flows through the copper pipe 41 into the evaporator 36 exploiting the difference in height between the high-temperature-side gas-liquid separator 40 and the evaporator 36. By repeating this cycle of events, even without the use of an external power for circulating the refrigerant, it is possible to release heat out of the refrigerator chamber, and thus it is possible to realize a low-power-consumption refrigerator.

**[0068]** Here, the use of latent heat obtained through liquefaction and vaporization of the refrigerant contributes to better heat transmission efficiency than when sensible heat is exploited. This makes it possible to efficiently transmit the heat in the high-temperature portion 2 to the high-temperature-side condenser 38, and thereby enhance the heat exchange efficiency of the refrigerator. Moreover, the high-temperature-side evaporator 36 and the high-temperature-side condenser 38 can be formed in the desired sizes. This makes it possible to efficiently transfer the heat in the low-temperature portion 2, of which the size is limited in consideration of the efficiency of the reverse Stirling cycle, to the air, which has low thermal conductivity, outside the refrigerator chamber. Furthermore, as the refrigerant, water is used, which is a non-flammable, non-toxic natural refrigerant. This helps realize a refrigerator friendly to humans and to the global environment.

**[0069]** The low-temperature-side gas-liquid separator 9 and the high-temperature-side gas-liquid separator 40 are provided for the purpose of increasing the flow rate of circulation of the refrigerant, and may be omitted. The flow rate of circulation of the refrigerant is determined by optimizing the difference in height between the low-temperature portion 3 and the low-temperature-side evaporator 7 and the difference in height between the high-temperature portion 2 and the high-temperature-side condenser 38.

**[0070]** The low-temperature-side evaporator 7 and the high-temperature-side condenser 38 are each formed in the shape of a box in their simplest form. However, forming them, for example, in the shape of a tube with fins helps increase their surface area and thereby enhance heat exchange efficiency.

**[0071]** The low-temperature-side condenser 32 and the high-temperature-side evaporator 36 may be removably kept in contact with, or brazed to, or formed integrally with the low-temperature portion 3 and the high-temperature portion 2, respectively. Alternatively, the low-temperature portion 3 or the high-temperature portion 2 may be formed in the shape of a doughnut having a cavity inside, with the refrigerant passed through the cavity, so as to serve simultaneously as a low-temperature-side condenser or a high-temperature-side



condenser, respectively.

[0072] The chiller system described above, provided with a low-temperature-side heat exchanger portion 30 or a high-temperature-side heat exchanger portion 31, is a highly versatile chiller system that finds wide application in many industrial fields, such as food distribution, environment testing, medicine, biotechnology, and semiconductor manufacture, as well as in home-use appliances and the like.

[0073] Next, a sixth embodiment of the present invention will be described with reference to the relevant drawing. Fig. 6 is a diagram schematically showing the configuration of the refrigerator of this embodiment. It is to be noted that, in the following description, a refrigerator incorporating the Stirling cooling apparatus of the fifth embodiment described above is taken up as an example.

[0074] In a back central portion of the refrigerator 42, the Stirling chiller 1 is arranged; in a back lower portion of the refrigerator 42, the low-temperature-side heat exchanger portion 30 is arranged; and, in the back upper portion of the refrigerator 42, the high-temperature-side heat exchanger portion 31 is arranged. The low-temperature-side evaporator 7 is arranged inside a cold air duct 43 inside the refrigerator chamber of the refrigerator 42, and the high-temperature-side condenser 38 is arranged inside an air exhaust duct 15 inside the refrigerator chamber of the refrigerator 42. The refrigerator chamber of the refrigerator 42 is divided into an upper section serving as a refrigerator compartment 44, a central section serving as a vegetables compartment 45, and a lower section serving as a freezer compartment 46. The cold air duct 43 communicates with the refrigerator compartment 44, the vegetables compartment 45, and the freezer compartment 46. The refrigerator compartment 44 and the vegetables compartment 45 communicate with each other.

[0075] When the Stirling chiller 1 is started, as described earlier, the heat produced in the high-temperature portion 2 is released through the high-temperature-side condenser 38 to the air surrounding it. Simultaneously, a fan 12 discharges the warm air inside the air exhaust duct 15 out of the refrigerator chamber of the refrigerator 42 and takes in the air outside refrigerator chamber of the refrigerator 42 to prompt heat exchange. The fan 12 may be omitted; in that case, the air inside the air exhaust duct 15 and the air outside the refrigerator chamber of the refrigerator 42 are circulated by natural convection.

[0076] On the other hand, as described earlier, the cold produced in the low-temperature portion 3 is transferred through the low-temperature-side evaporator 7 to the air inside the cold air duct 43. Simultaneously, a cold air circulation fan 13 passes the cold air inside the cold air duct 43 into the freezer compartment 46, and passes part of the cold air into the refrigerator compartment 44. The cold air passed into the refrigerator compartment 44 then flows into the vegetables compartment 45, and

then flows through the cold air duct 43 back to near the evaporator 7.

[0077] When the low-temperature-side evaporator 7 is defrosted, drained water is discharged out of the refrigerator chamber of the refrigerator 42 through a drain outlet provided in a bottom portion of the refrigerator 42.

[0078] In this way, by incorporating the chiller system of the fifth embodiment in a large, horizontal-type refrigerator, it is possible to effectively exploit the height of the refrigerator in the arrangement of the low-temperature-side heat exchanger portion 30 and the high-temperature-side heat exchanger portion 31. Moreover, by arranging the freezer compartment 46 nearest to the low-temperature-side evaporator 7 and arranging the vegetables compartment 45 under the refrigerator compartment 44, it is possible to effectively use the cold air inside the refrigerator chamber of the refrigerator 42.

#### Industrial applicability

[0079] As described above, according to the present invention, the use of latent heat obtained through vaporization and liquefaction of the refrigerant contributes to better heat transmission efficiency than when sensible heat is exploited. Thus, cold is efficiently transferred to inside the refrigerator or cooler chamber, or heat is efficiently released to outside the refrigerator or cooler chamber. This helps enhance the heat exchange efficiency of refrigerators. Moreover, the condenser and the evaporator can be formed in the desired sizes. This makes it possible to efficiently transfer the heat in the low-temperature and high-temperature portions, of which the sizes are limited in consideration of the efficiency of the reverse Stirling cycle, to air, which has low thermal conductivity. This helps realize large-capacity refrigerators. Moreover, the refrigerant is circulated by exploiting the difference in height, without the use of external power prepared specially for the circulation of the refrigerant. This helps realize low-power-consumption refrigerators. Moreover, the provision of the gas-liquid separator ensures stable circulation of the refrigerant without the use of a means for forcibly circulating the refrigerant. This helps reduce costs and save energy. Moreover, the use of carbon dioxide or water, which is a non-flammable, non-toxic natural refrigerant, as the refrigerant helps realize refrigerators friendly to humans and to the global environment. Moreover, by dividing the refrigerator chamber into an upper section serving as a refrigerator compartment, a middle section serving as a vegetables compartment, and a lower section serving as a freezer compartment, it is possible to effectively use the cold air inside the refrigerator chamber. Moreover, the incorporation of the Stirling cooling apparatus helps realize coolers that produce far lower noise, that have far simpler configurations, and that save far more space than conventional vapor-compression-type coolers employing a compressor.

## Claims

1. A Stirling cooling apparatus comprising:
  - a Stirling chiller having a high-temperature portion whose temperature rises as the Stirling chiller is operated and a low-temperature portion whose temperature falls as the Stirling chiller is operated;
  - an evaporator provided integrally with or separately from the Stirling chiller; and
  - a refrigerant circulation circuit for transferring cold produced by the low-temperature portion to the evaporator by means of a refrigerant circulated between the low-temperature portion and the evaporator by a refrigerant circulation means,

wherein the refrigerant is a natural refrigerant that liquefies in the low-temperature portion and vaporizes in the evaporator.
2. A Stirling cooling apparatus as claimed in claim 1, wherein the natural refrigerant is carbon dioxide.
3. A Stirling cooling apparatus as claimed in claim 1, wherein the refrigerant is cooled to a predetermined supercooled state by the low-temperature portion.
4. A Stirling cooling apparatus as claimed in claim 1, wherein, in a path within the refrigerant circulation circuit which the refrigerant takes after flowing out of the low-temperature portion before flowing into the refrigerant circulation means, a gas-liquid separator is arranged that separates the refrigerant into a gas phase and a liquid phase and that permits only the refrigerant in the liquid phase to be supplied to the refrigerant circulation means.
5. A Stirling cooling apparatus as claimed in claim 1, wherein the refrigerant circulation means is composed of a gas-liquid separator, which is arranged in a path within the refrigerant circulation circuit which the refrigerant takes after flowing out of the low-temperature portion before flowing into the refrigerant circulation means and in a position higher than the evaporator, and which separates the refrigerant into a gas phase and a liquid phase and permits only the refrigerant in the liquid phase to be supplied to the refrigerant circulation means, and
  - a difference in specific gravity between the refrigerant in the liquid phase at an outlet of the gas-liquid separator and the refrigerant inside the evaporator is exploited as a power source for circulating the refrigerant.
6. A refrigerator incorporating a Stirling cooling apparatus as claimed in claim 1.
7. A refrigerator incorporating a Stirling chiller, wherein a low-temperature-side evaporator for releasing cold to inside a refrigerator chamber is arranged in a position lower than a low-temperature portion of the Stirling chiller which produces the cold,
  - a circuit is arranged in such a way that a refrigerant is circulated between the low-temperature-side evaporator and the low-temperature portion, and
  - the refrigerant liquefies by absorbing the cold in the low-temperature portion, then flows to the low-temperature-side evaporator by exploiting a difference in height between the low-temperature portion and the low-temperature-side evaporator, then vaporizes by releasing the cold inside the low-temperature-side evaporator, and then flows in a vaporized state back to the low-temperature portion.
8. A refrigerator as claimed in claim 7, wherein the refrigerant is carbon dioxide.
9. A refrigerator incorporating a Stirling chiller, wherein a high-temperature-side condenser for releasing heat to outside a refrigerator chamber is arranged in a position higher than a high-temperature portion of the Stirling chiller which produces the heat,
  - a circuit is arranged in such a way that a refrigerant is circulated between the high-temperature-side condenser and the high-temperature portion, and
  - the refrigerant vaporizes by absorbing the heat in the high-temperature portion, then flows in a vaporized state to the high-temperature-side condenser, then liquefies by releasing the heat inside the high-temperature-side condenser, and then flows back to the high-temperature portion by exploiting a difference in height between the high-temperature-side condenser and the high-temperature portion.
10. A refrigerator as claimed in claim 9, wherein the refrigerant is water.
11. A refrigerator incorporating a Stirling chiller, wherein a low-temperature-side evaporator for releasing cold to inside a refrigerator chamber is arranged in a position lower than a low-temperature portion of the Stirling chiller which produces the cold,

- a circuit is arranged in such a way that a first refrigerant is circulated between the low-temperature-side evaporator and the low-temperature portion,  
 the first refrigerant liquefies by absorbing the cold in the low-temperature portion, then flows to the low-temperature-side evaporator by exploiting a difference in height between the low-temperature portion and the low-temperature-side evaporator, then vaporizes by releasing the cold inside the low-temperature-side evaporator, and then flows in a vaporized state back to the low-temperature portion,  
 a high-temperature-side condenser for releasing heat to outside the refrigerator chamber is arranged in a position higher than a high-temperature portion of the Stirling chiller which produces the heat,  
 a circuit is arranged in such a way that a second refrigerant is circulated between the high-temperature-side condenser and the high-temperature portion, and  
 the second refrigerant vaporizes by absorbing the heat in the high-temperature portion, then flows in a vaporized state to the high-temperature-side condenser, then liquefies by releasing the heat inside the high-temperature-side condenser, and then flows back to the high-temperature portion by exploiting a difference in height between the high-temperature-side condenser and the high-temperature portion.
12. A refrigerator as claimed in claim 11,  
 wherein the first refrigerant is carbon dioxide,  
 and the second refrigerant is water.
13. A refrigerator as claimed in claim 7 or 11,  
 wherein, in a path within the circuit which the refrigerant takes while flowing from the low-temperature portion to the low-temperature-side evaporator, a low-temperature-side gas-liquid separator is arranged that separates the vaporized and liquefied refrigerant.
14. A refrigerator as claimed in claim 9 or 11,  
 wherein, in a path within the circuit which the refrigerant takes while flowing from the high-side condenser to the high-temperature portion, a high-temperature-side gas-liquid separator is arranged that separates the vaporized and liquefied refrigerant.
15. A refrigerator as claimed in one of claims 7, 9, or 11,  
 wherein the refrigerator chamber is divided into an upper section serving as a refrigerator compartment, a middle section serving as a vegetables compartment, and a lower section serving as a freezer compartment.

16. A refrigerator as claimed in one of claims 7, 9, or 11,  
 wherein the refrigerator chamber is divided into an upper section serving as a refrigerator compartment, a middle section serving as a vegetables compartment, and a lower section serving as a freezer compartment, and

within the refrigerator chamber, the cold is introduced, as cold air, first into both the freezer and refrigerator compartments and then from the refrigerator compartment to the vegetables compartment.

FIG. 1

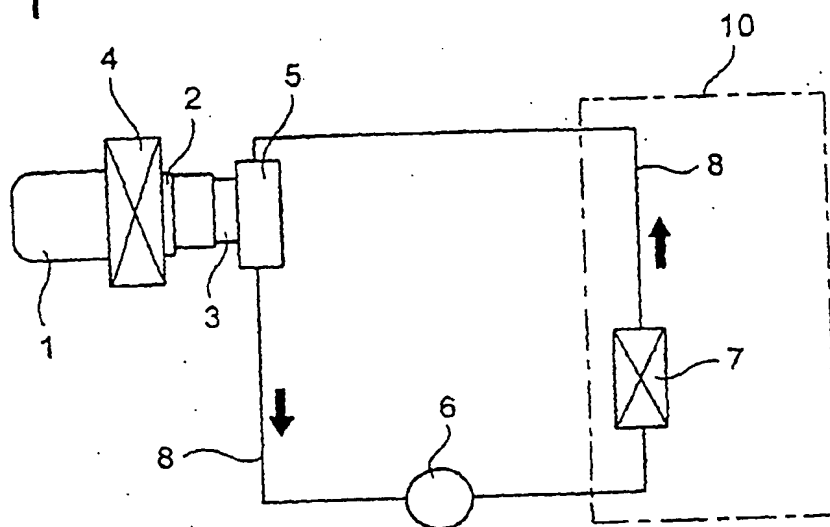


FIG. 2

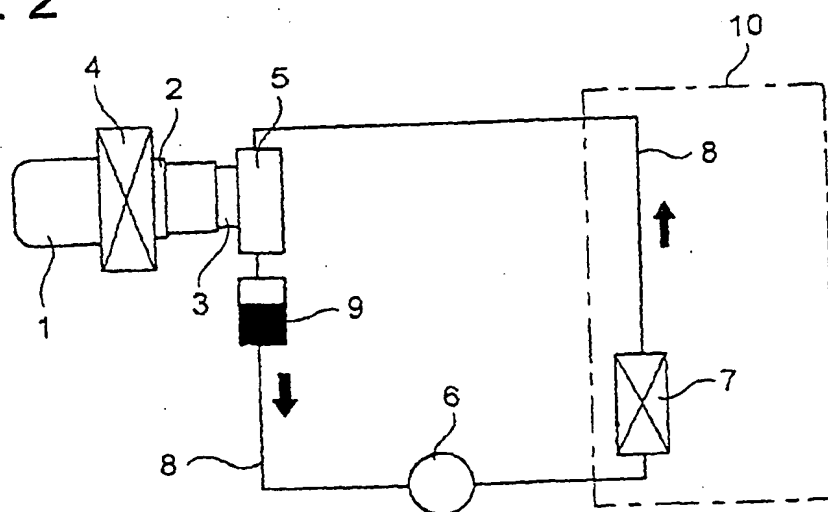


FIG. 3

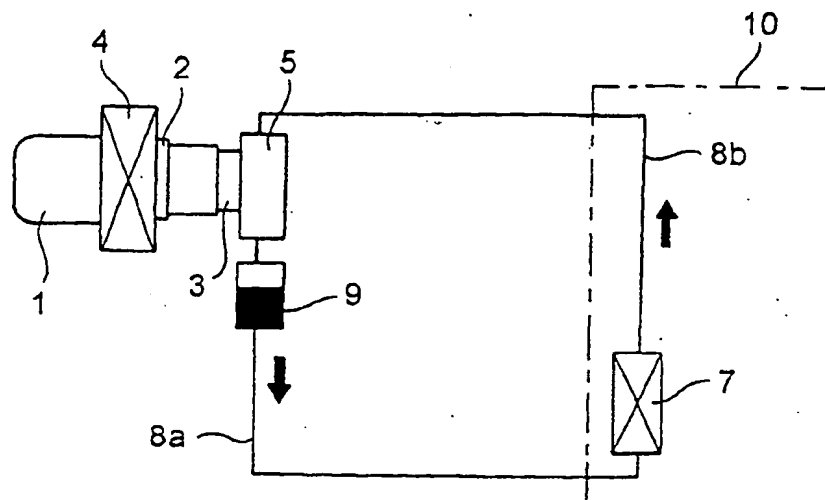


FIG. 4

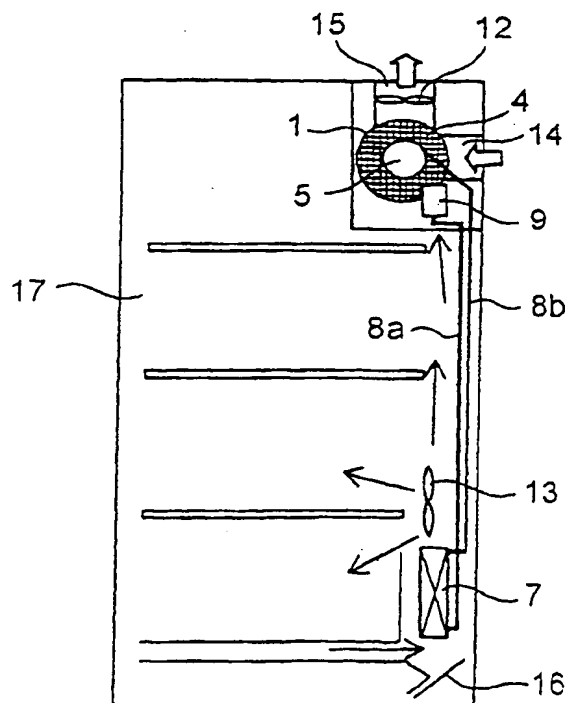


FIG. 5

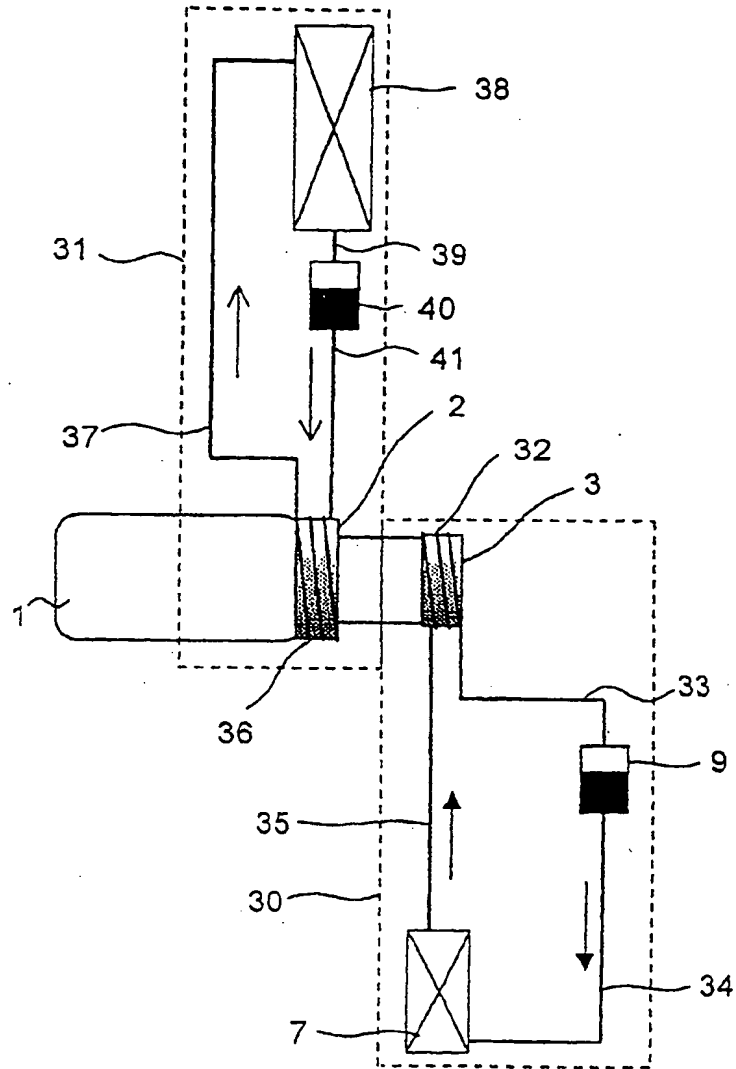


FIG. 6

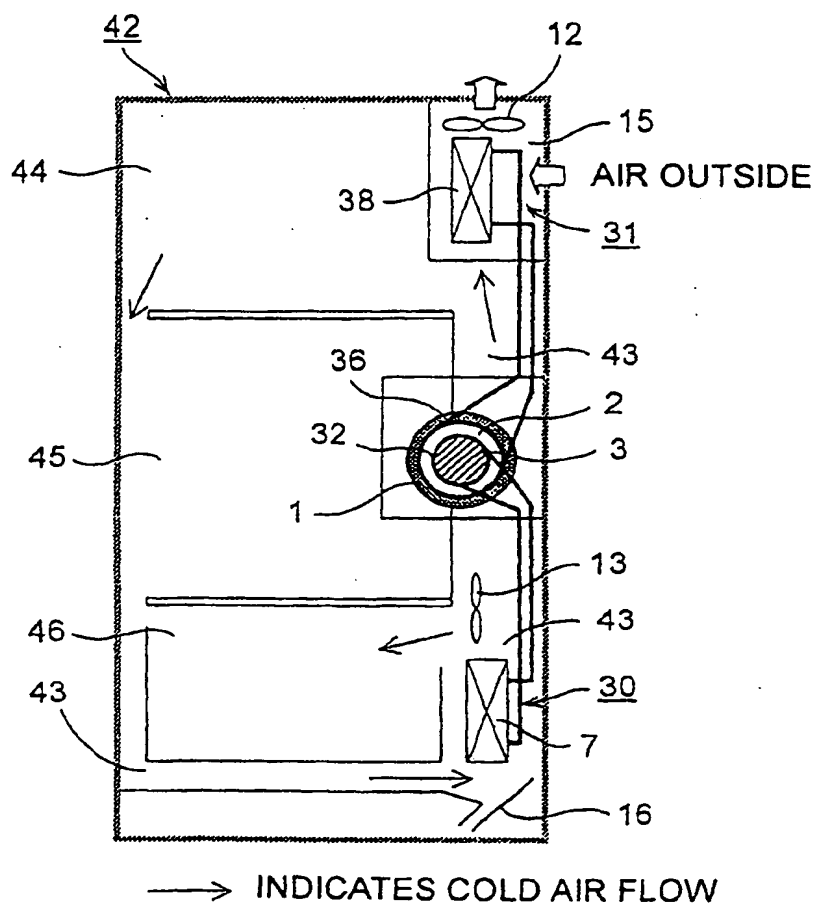
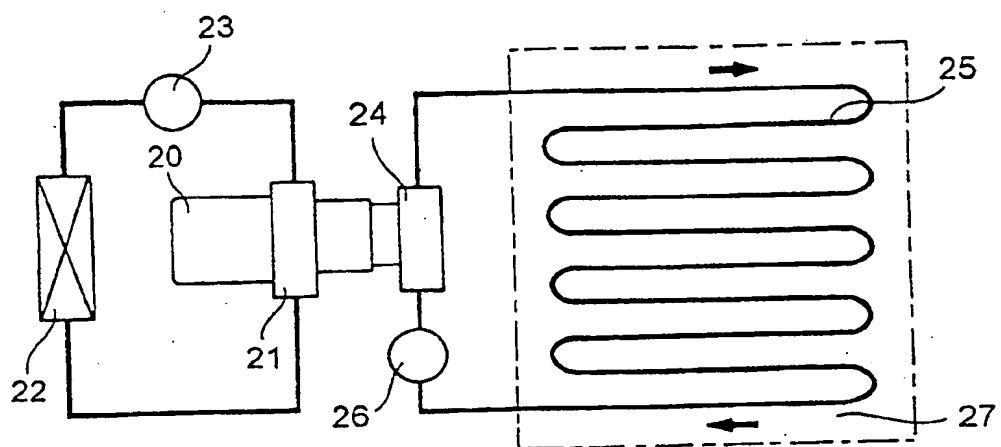


FIG. 7





## INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP01/06994

<b>A. CLASSIFICATION OF SUBJECT MATTER</b> Int.Cl <sup>7</sup> F25B 9/14, F25D 11/00, 17/00		
According to International Patent Classification (IPC) or to both national classification and IPC		
<b>B. FIELDS SEARCHED</b> Minimum documentation searched (classification system followed by classification symbols) Int.Cl <sup>7</sup> F25B 9/14, F25D 11/00, 17/00		
Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched Jitsuyo Shinan Koho 1926-2001 Jitsuyo Shinan Toroku Koho 1996-2001 Kokai Jitsuyo Shinan Koho 1971-2001 Toroku Jitsuyo Shinan Koho 1994-2001		
Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)		
<b>C. DOCUMENTS CONSIDERED TO BE RELEVANT</b>		
Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
P, X	JP 2001-33139 A (Global Cooling BV), 09 February, 2001 (09.02.01), page 4, column 5, line 31 to column 6, line 33 (Family: none)	1, 2, 6-8
P, Y		3
A	JP 2000-193360 A (Sharp Corporation), 14 July, 2000 (14.07.00), page 5, column 7, lines 1 to 7 (Family: none)	1-16
A	JP 7-180921 A (Toshiba Corporation), 18 July, 1995 (18.07.95), page 4, column 5, line 41 to column 6, line 8 (Family: none)	1-16
A	JP 63-83566 A (Toshiba Corporation), 14 April, 1988 (14.04.88), page 3, upper right column, line 12 to page 3, lower left column, line 15 (Family: none)	1, 7, 9, 11
<input type="checkbox"/> Further documents are listed in the continuation of Box C. <input type="checkbox"/> See patent family annex.		
* Special categories of cited documents: "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art "&" document member of the same patent family	
Date of the actual completion of the international search 01 November, 2001 (01.11.01)		Date of mailing of the international search report 13 November, 2001 (13.11.01)
Name and mailing address of the ISA/ Japanese Patent Office		Authorized officer
Facsimile No.		Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)